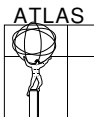# Physics activities on ATLAS
I. Hinchliffe

Relation to Computing/Project

Current Activities

- Monte-Carlo support, new Framework
- Simulation studies
  - $\sin^2\theta_W$
  - Extra Dimensions
  - Lepton flavor violation

Relation between Physics and Computing

The software and hardware are not ends in themselves, they are a service that enables physics to get done

Physicist involvement is essential during requirements and design phase

Ongoing physics simulation provides testing and requirements

Functioning simulation code is always needed in case of detector changes

- Recently the crack between the central and forward calorimeters widened
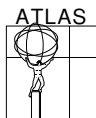
Large scale tests are provided by Mock Data Challenges

Expected to begin in 2003

Essential for testing complete system

Will provide valuable experience for Regional Center in data access and usage patterns

Interaction of Tier 1/Tier2/CERN can also be tested in detail

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Physicist Support

Some support of specifically Physics related activities are needed In particular Monte-Carlo event generators (written by persons outside the collaboration) must be integrated into and maintained within the ATLAS system.

This support must be continuous and backed by a real commitment

Must be part of the project

Based on other experiments experience we expect 1 FTE to be the US share.

I am Coordinator of the group that is responsible for this in ATLAS
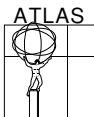
I am also ATLAS Deputy Physics Cooridator

I have no (close to) full time person working on this in the US
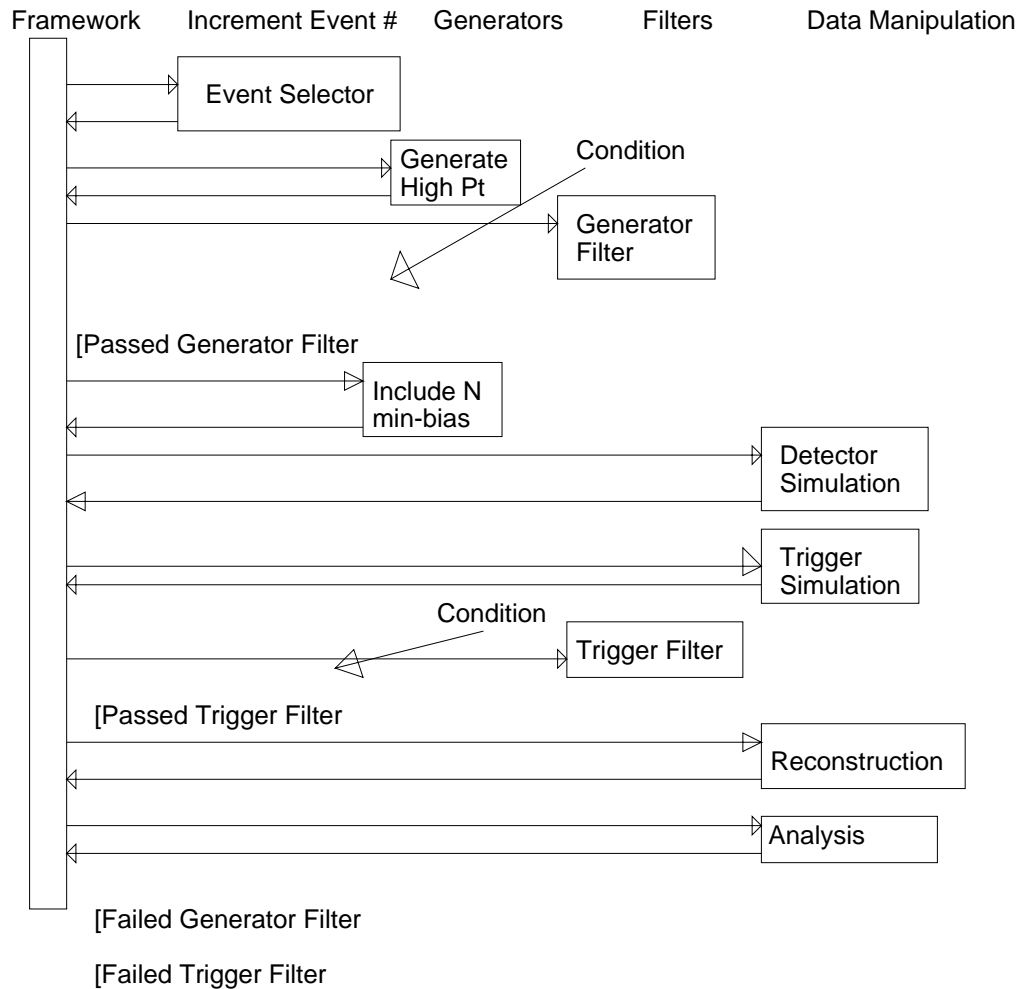
1 FTE represents a fair US contribution to the effort

Current Activities – Monte Carlos and Athena

- Output from all generators in common format

- Use one generator for High P_t process and another for MinBias

- Read events from pre-existing files OR generate on the fly

- Use same interface for full or fast simulation

- Stop at any stage in Generation/Simulation/Analysis chain, write output and then continue in separate job

- Add selection modules (filters) to stop event processing as early as possible if event fails to meet requirements

- Select Generator at run-time

- Set Generator parameters at run-time

- Optionally write of parts of GeneratorEvent (requirement on convertor)

Example of Simulation Flow

Framework | Increment Event # | Generators | Filters | Data Manipulation

Event Selector

Generate High Pt

Condition

Generator Filter

[Passed Generator Filter

Include N min-bias

Detector Simulation

Trigger Simulation

Condition

Trigger Filter

[Passed Trigger Filter

Reconstruction

Analysis

[Failed Generator Filter

[Failed Trigger Filter

Sequence Diagram for single physics event

Note: Must also support other flows, *eg* reading MinBias hits and digits and merging after simulation

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Integration into Athena: Base Class for Generator Modules

- **Base class GenModule implements common functionality:**

  - Access HepMC ParticleTable

  - Instantiate CLHEP Random Engine

  - Throw Poisson (if required) for Number of Events

  - Call Generator (see below)

  - Load event into Transient Store

- **Provides hooks for child class (virtual methods):**

  - genInitialize() [Once at start of job]

  - genFinalize() [Once at end of job]

  - callGenerator() [Every event]

  - fillEvt(GeneratorEvent* evt) [Every event]

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Adding Monte Carlo Information to Transient Store

- HepMC defines generator independent description of event

- In order to add to Transient Store, define a class

  <p style="color:red">McEvent:: public ContainedObject</p>
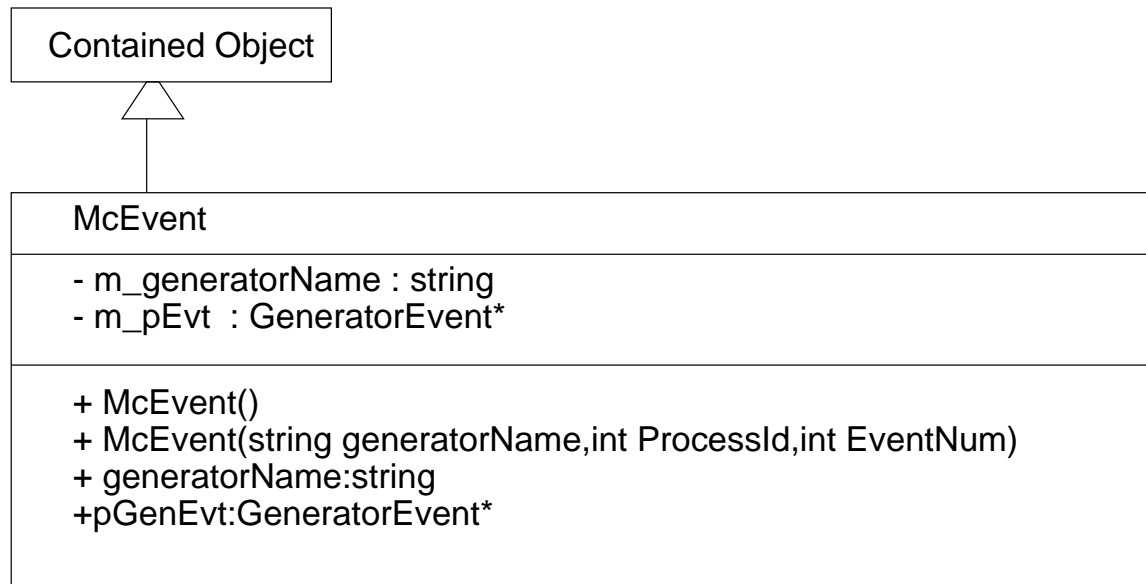
  that contains generator name and HepMC::GeneratorEvent

- Since several McEvents within a given physics event (hard scatter plus N min bias):

  <p style="color:red">typedef ObjectVector<McEvent> McEventCollection</p>

  Interface is identical to STL vector

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McEvent Class Diagram

```
┌─────────────────────┐
│  Contained Object   │
└─────────────────────┘
          △
          │
┌──────────────────────────────────────────────────────────────┐
│  McEvent                                                       │
├──────────────────────────────────────────────────────────────┤
│  - m_generatorName : string                                    │
│  - m_pEvt  : GeneratorEvent*                                   │
├──────────────────────────────────────────────────────────────┤
│  + McEvent()                                                   │
│  + McEvent(string generatorName,int ProcessId,int EventNum)    │
│  + generatorName:string                                        │
│  +pGenEvt:GeneratorEvent*                                      │
│                                                                │
└──────────────────────────────────────────────────────────────┘
```

Generator Specific SubClasses

- Status:

  - EventService for generating event header (Event/EventManagement classes) (Done)

  - Single Particle Gun (Done)

  - Isajet (Done)

  - Pythia (Preliminary Version Done)

    * Provided Interface to pass parameters at run-time

    * Now gets parameters via JobOptions service (Scripting interface will improve this)

  - Generator Level Filter Example (In Progress)

  - Herwig – September

  - Pythia7 – Good task for a new person

  - Persistify HepMC
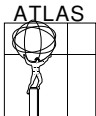
Atlas Software Integration

Functioning Packages Installed in CVS

- External/Pythia, External/Isajet, External/StdHep
- Generators/Pythia_i,
  Generators/GeneratorModules, Generators/GeneratorUtilties
- Generators/test (builds binaries)
- No doc yet

Note: New versions of Pythia (6.129), Isajet (7.51), Herwig (6.1) exist as an external package in /afs/cern.ch/atlas/offline/external/

Recent Phyiscs Activity

Several U.S.ATLAS members are active in leadership of the various
physics groups
J. Parsons – Top and other Heavy quarks and Leptons
F. Paige – Supersymmetry

Three examples from recent US-ATLAS physics activity

- Extended rapidity coverage and measurement of $sin^2\theta_W$ (Sliwa, Riley, Baur)

- Lepton Flavor violation (Paige, IH)

- Extra Dimensions (Vacavant, IH)

Forward Backward asymmetry in Z decay
Sliwa, Riley, Baur

Exploit Z production at LHC to measure $sin^2\theta_W$ in leptonic final states

Current error from LEP $\delta sin^2\Theta_{eff}^{lep} = 2.3 \times 10^{-4}$.

Large LHC event rate $\sigma \times BR(Z \to e^+e^-) = 1.6$ nb

Measure forward backward asymmetry in leptonic final states $A_{FB} = \frac{F-B}{F+B}$

Need to know quark direction (defines z)

At Tevatron $p\overline{p}$ generates a preferred direction for the incoming quark (anti-quark) and hence asymmetry

at LHC Asymmetry is zero if integrated over all Z rapidity.

F-B asymmetry is a function of rapidity of Z

Large rapidity implies that quark is in Z direction and $A_{FB} \neq 0$

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Rapidity of Z depends on electron acceptance.
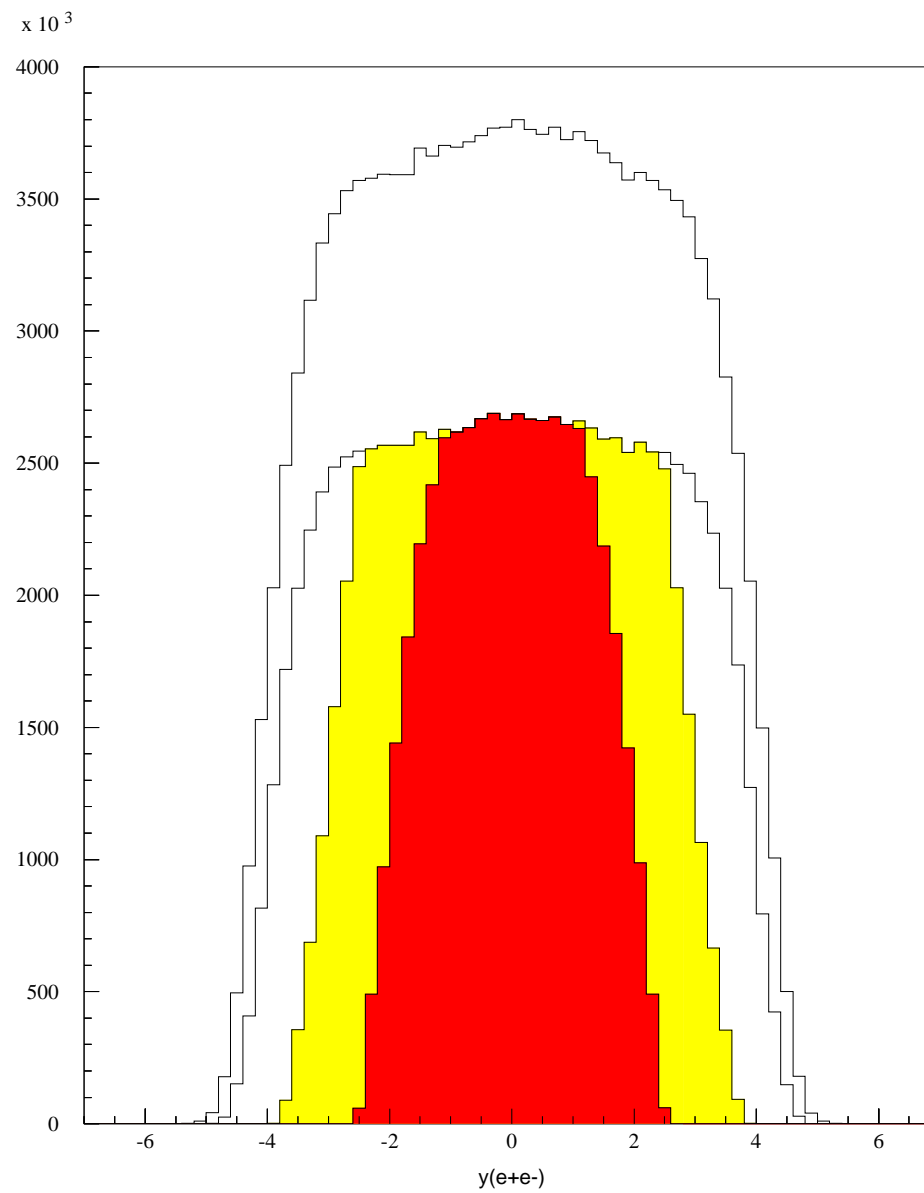
Figure shows: both electrons anywhere;

both in $|\eta| < 4.9$;

one in $|\eta| < 4.9$ other $|\eta| < 2.5$;

both in $|\eta| < 2.5$;

both in $|\eta| < 4.9$ and $|\eta_Z| > 1$

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x 10³

4000

3500

3000

2500

2000

1500

1000

500

0

-6   -4   -2   0   2   4   6

y(e+e-)

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Might be possible to identify electrons in $2.5 < \eta < 4.9$

No charge information (outside tracking region)

Extend region by using one electron in $|\eta| < 2.5$, assume other one has opposite charge

Measurable asymmetry increases:
   shown as a function of η_Z for standard acceptance (triangles) and extended (squares)

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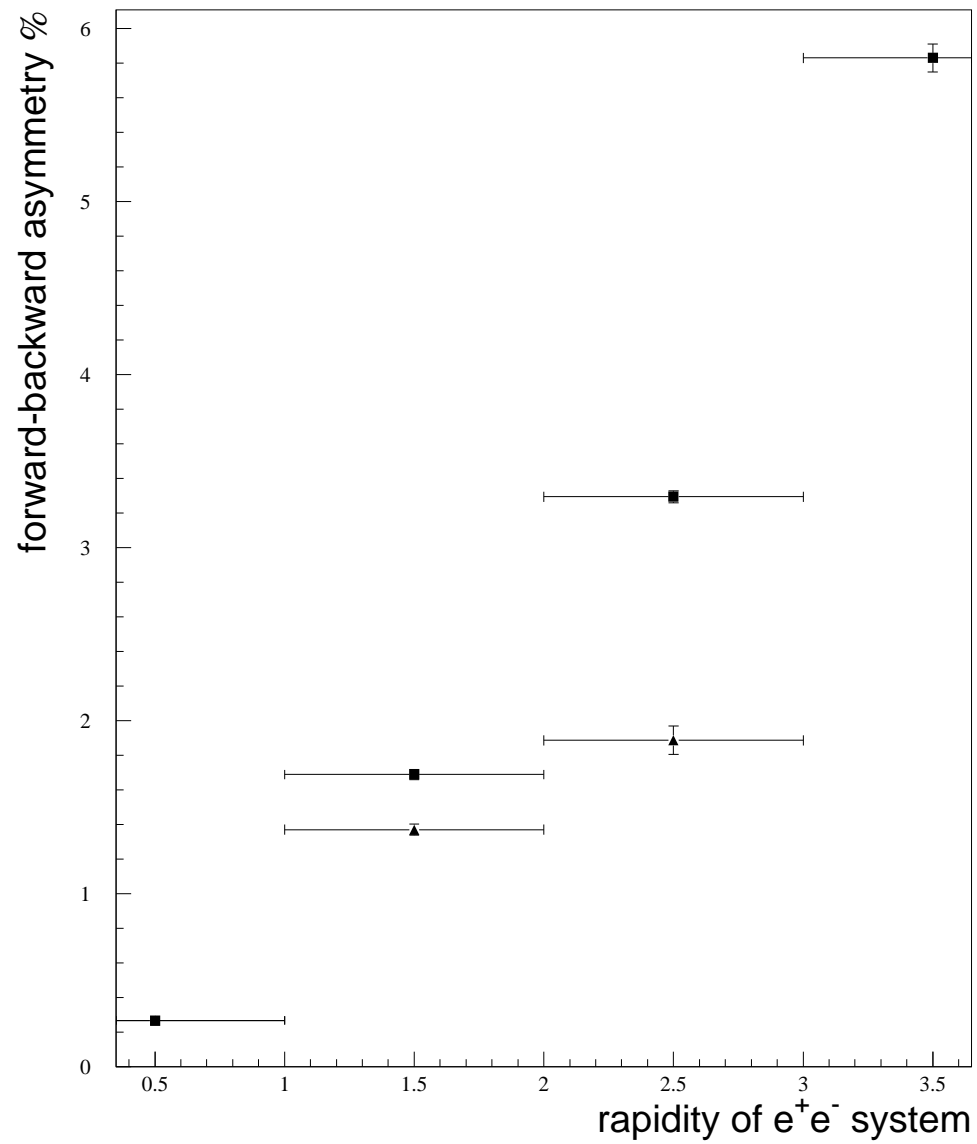
50% detection efficiency and jet rejection ~ 100 assumed in extended region

Should reach

$$\delta sin^2\Theta_{eff}^{lep} = 2.3 \times 10^{-4}.$$

for 100 fb^{-1}

without extended coverage, sensitivity is worse than current error.

Detailed study needed to assess viability

Could significantly extend understanding of precision electroweak tests

Extra Dimensions

Introduction – Why extra dimensions?

Two types of models "large" and "warped"

Generic Signals are Missing energy or resonances

Both studied in ATLAS, only former discussed here

Arkani-Hamed, Dimopolous,Dvali

Guidice, Wells, Ratazzi Mirabelli, Perlstein, Peskin Han, Lykken, Zhang

Randall Sundrum

Hewitt..
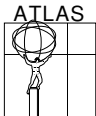
Why extra dimensions?

- Why not?

- String people believe that $d = 10$

- Extra dimensions compact on some size R

- $R \sim 1/M_P, M_{GUT}$ – unobservable

- Try to solve hierarchy problem: $M_W << M_P$ or $G_N << G_F$, why are weak interactions so strong??

- Or Why is gravity so weak?.

- Make G_N an effective coupling in $D = 4$ or generate e^{-35}

- Two different classes of models: large extra and warped extra dimensions offer different solutions

- LHC signals are different: Missing energy or Graviton resonances

Sizes and Scales:Large extra dimensions

- d extra dimensions of size R (factorizable geometry)

- Gauss law must work in 4 and $4+d$ dimensions

$$\frac{1}{M_P^2 r^2} \text{ vs. } \frac{1}{M_D^{d+2} r^{d+2}}$$

- M_D (~ 1 TeV) is fundamental Planck scale; Must get same value when $r = R$

- Hence $M_P^2 = M_D^{d+2} R^d$; $M_D \sim 1$ TeV,
  d=2 $\Rightarrow R = 1\mu m$
  d=4 $\Rightarrow R \sim 10^{-5}\mu m$

- New Scale problem RM_D is huge; one hierarchy problem replaced by another.

- Consistent with data – Gravity has only been tested in Lab experiments on scales $> 1mm$

Model independent signatures: Large extra dimensions

- $ds^2 = \eta_{\mu,\nu} dx^\mu dx^\nu + (dy_1 dy_1 + \cdots)$
  Massless particle in 4+d dimensions $0 = E^2 - p_4^2 - p_d^2$
  Extra dim is compact $\Rightarrow p_d^2 \sim n/d^2 \Rightarrow$ tower of massive states

- In $4D$, looks like a set of particles with very small mass

- Density of states is large

$$n(E) \sim E^d \frac{M_{pl}^2}{M_D^{d+2}}$$

- Rate to emit any one state is small – Gravitational coupling

- But many states at high energy

- $e.g \; gg \to gnG, \; q\bar{q} \to \gamma nG$
  state "nG" is any one of the states. Rates depend only on d and M_D

- Signal is "monojet" or photon + missing E_T Implemented is ISAJET:

- Calculation unreliable for $\hat{s} \sim M_D$ as other new physics must enter

Signatures continued

- Exchange of the tower of states can distort scatterings

  $e.g.\ gg \rightarrow gg$

  Effects easier to measure in $e^+e^- \rightarrow \mu^+\mu^-$
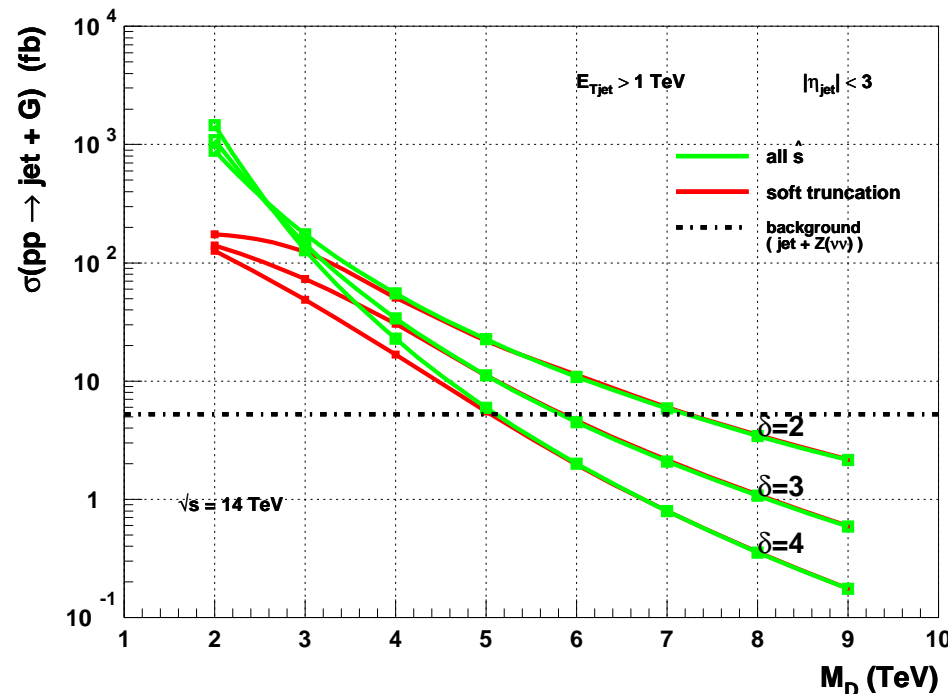
  Can distort the jet cross-sections, but competing with gluon exchange is tough

  <div align="center">What happens when $E \sim M_D$</div>

- Gravitational effects – Model independent

- Other new interactions – Model dependent – What happens to SM at M_D?

- Other model dependent effects at low energy $e.g.$ LEP

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Processes such as $qg \to qG$ or $q\bar{q} \to \gamma G$ give missing energy signatures

Plot shows jets with $P_T > 1$ TeV and $E_{T_{miss}} > 100$ GeV

Standard model background (horizontal line) is dominated by $Z + jets$

Small M_D implies that other new states of mass M_D can be produced and rates are unreliable (Region where red and green curves differ)
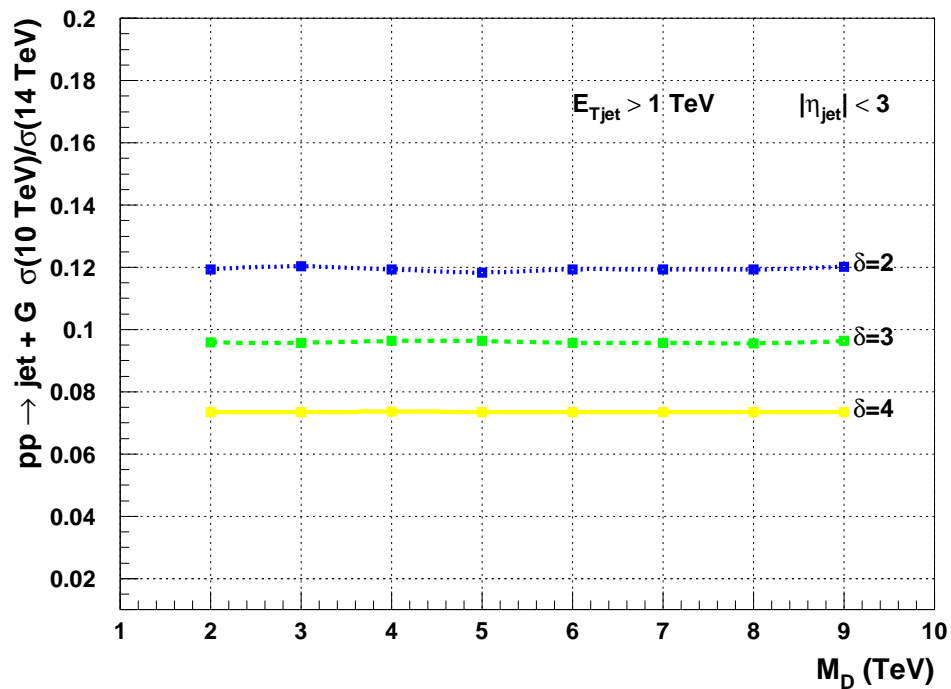
Sensitivity

δ	M_D^{min} (TeV)	M_D^{max} (TeV)	$R_{compact}$
2	~ 4	7.5	10 μm
3	~ 4.5	5.9	300 pm
4	~ 5	5.3	1 pm

Difficult to distinguish M_D from δ because parton center of mass energy
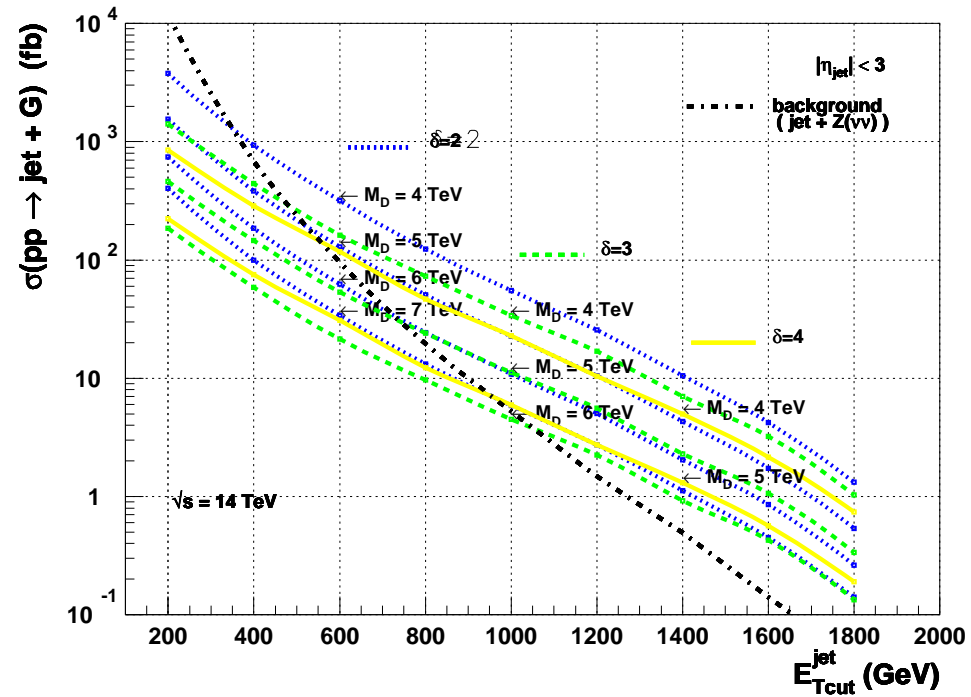
is not fixed

Only hope is to lower LHC energy and look at ratio of rates

Almost independent of M_D for fixed δ

Lepton Flavor Violation

Existence of neutrino oscillations implies lepton number is not conserved

Atmospheric neutrino oscillations point to $\nu_\mu - \nu_{tau}$

Hence expect τ and μ not conserved
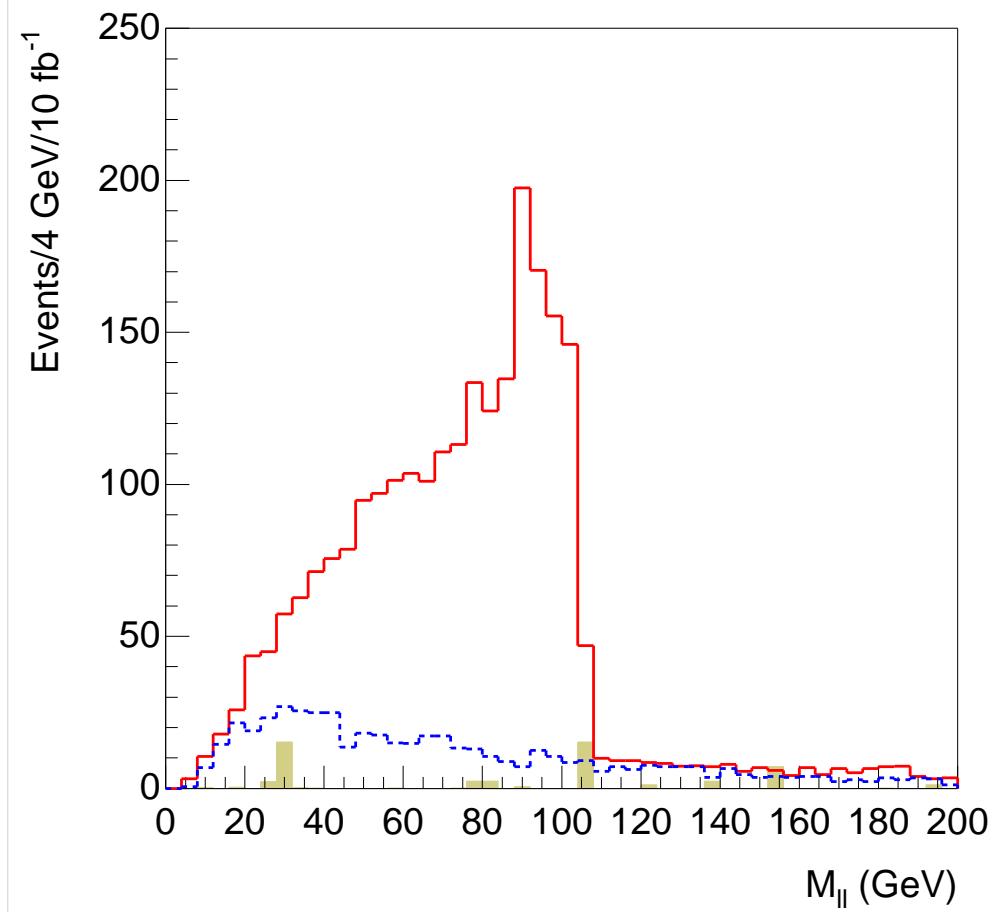
Should expect $\tau \to \mu\gamma$
very hard at LHC due to background from radiative tau decays

Look for direct consequences of $\mu - \tau$ non-universality

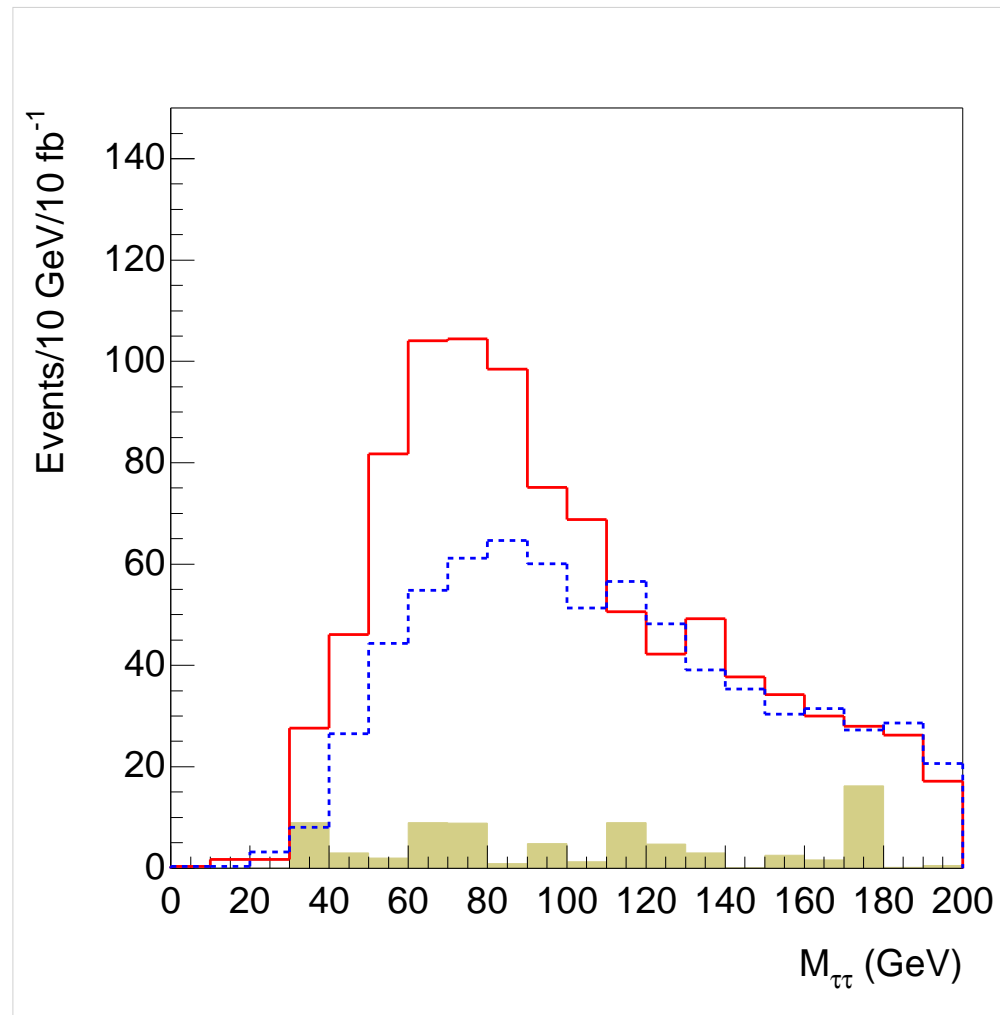In SUSY dominant source of slepton is from squark decay $\tilde{\chi}_2^0 \to \tilde{\ell}\ell$

Subsequent decay of slepton produces opposite sign same flavor lepton pair of characteristic invarient mass.

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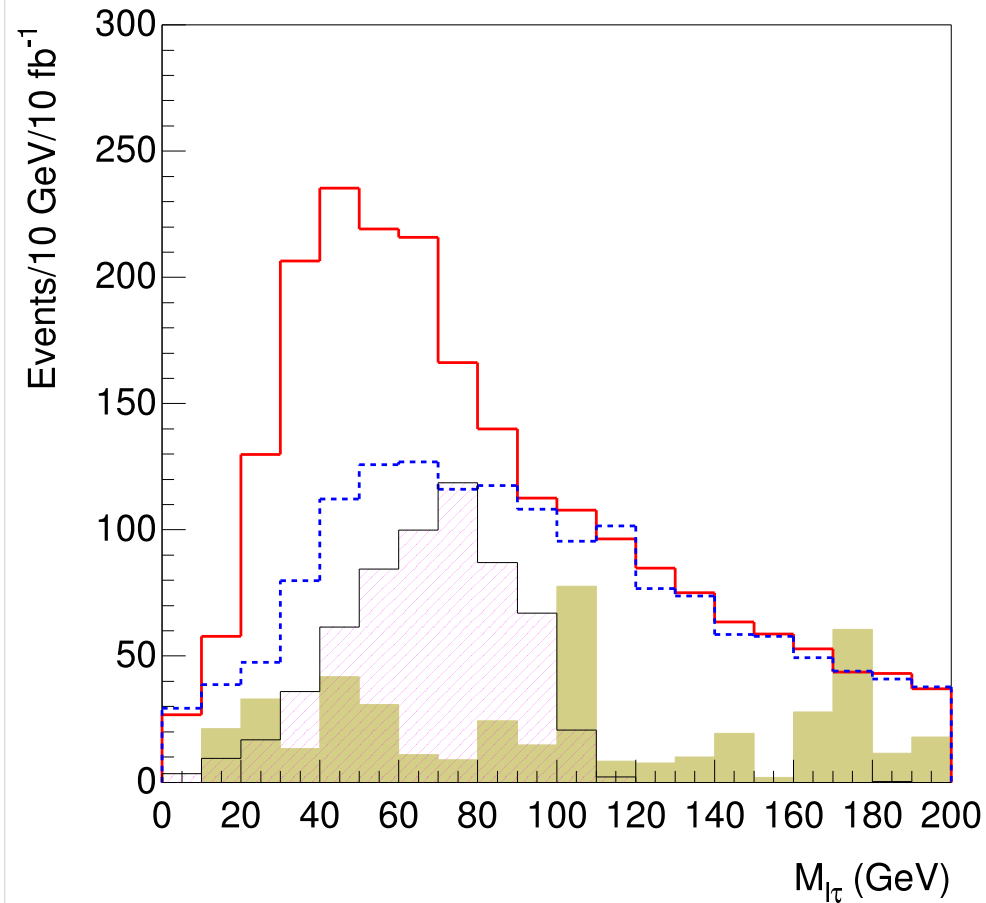
$\mu^-\mu^-$, $\mu^+\mu^-$,

Hadronic decays of tau produces smeared out struture due to loss by neutrinos

If lepton flavor violation present then $\tilde{\chi}_2^0 \to \tilde{\tau}\mu$ Look at invarient mass of "hadronic tau" and muon

signal $\tau^+\mu^-$, $\tau^+\mu^-$ from $\tau\tau$, $\tau^+\mu^+$

No structure in "hadronic tau" and electron

Subract $\tau^+ e^-$ from $\tau^+ \mu^-$ and see excess

30 fb^{-1} corresponds to 3.3% for BR $\tilde{\chi}_2^0 \to \tilde{\tau}\mu$ equivalent to BR $\tau \to \mu\gamma = 10^{-9}$ way beyond sensitivity